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# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

## TECHNICAL NOTE

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## A METALLURGICAL INVESTIGATION OF TWO CONTOUR-FORGED GAS-TURBINE DISCS OF 19-9DL ALLOY

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## SUMMARY

It has been found that the properties of heat-resisting alloys are dependent to a large extent on the conditions of fabrication. Because the large size of certain gas-turbine rotors has introduced fabrication procedures for which information is not available, a research program was begun at the University of Michigan to ascertain the properties of the better alloys in the form of large forgings.

On the basis of prior investigations of bar stock and a cheese forging, 19-9DL alloy was thought to have suitable properties for the discs for the rotors of gas turbines for jet engines. Arrangements were made to have a series of such discs forged by The Canton Drop Forging and Manufacturing Company. Two of these discs, differing in that one was hot-cold-worked at 1650° F and the other at 1250° F, were cut up for experimental purposes. One-quarter of each disc was supplied to the University of Michigan for investigation for the NACA. The principal objects of this investigation were to determine the level of properties developed in large contour forgings of 19-9DL alloy, to evaluate the effect of the temperature of hot-cold-work in these large forgings, and to show the degree to which the properties of bar stock could be reproduced in large forgings.

Analysis of data indicated that when processed under similar conditions the properties of 19-9DL bar stock are reproduced quite well in the large forgings. The relative properties of the discs of 19-9DL and discs of other alloys depended on the heat treatment and hot-cold-work during forging as well as on chemical composition.

## INTRODUCTION

Alloy 19-9DL is one of the lower alloyed materials which has been developed for high-temperature service. Properties obtained from bar stock and a large cheese forging have indicated that the alloy was suitable for rotors for the gas turbines of jet engines for aircraft. (See reference 1.) For this reason large contour rotor forgings for a jet engine were manufactured for experimental purposes at The Canton Drop Forging and Manufacturing Company.

Prior experience with the alloy, and with other similar alloys, had shown that its properties depend to a large extent on the processing conditions and heat-treating history during fabrication. For this reason one forging was prepared with hot-cold-work at 1250° F and another with hot-cold-work at 1650° F. Sections of discs with both types of fabrication were submitted for study at the University of Michigan for the NACA. The principal objects of this investigation were to determine the level of properties developed in large contour forgings of 19-9DL alloy, to evaluate the effect of the temperature of hot-cold-work in these large forgings, and to show the degree to which the properties of bar stock could be reproduced in large forgings.

The investigation was limited to room temperature and 1200° F. These are the two temperatures at which properties of materials have been considered indicative of the performances of rotor discs in current jet engines. Satisfactory room-temperature properties are needed to withstand the high stresses existing at low temperatures near the hub. Good properties at 1200° F are believed to be a necessary requirement of material near the rim of the discs.

The discs were forged by The Canton Drop Forging and Manufacturing Company. The U. S. Air Forces, Air Materiel Command at Wright Field, in cooperation with the Universal-Cyclops Steel Corporation and the General Electric Company, arranged to furnish the test discs.

These large contour discs of 19-9DL alloy are part of a series of discs of various alloys which are being studied. The results obtained from investigations on large discs of 19-9DL, CSA, low-carbon N-155, and Timken alloys are given in references 1 to 5.

This work was conducted at the University of Michigan under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics.

## DESCRIPTION OF DISCS

Information concerning the two discs of 19-9DL alloy is summarized as follows:

Steel producer:

The Universal-Cyclops Steel Corporation, Bridgeville, Pennsylvania

Disc manufacturer:

The Canton Drop Forging and Manufacturing Company, Canton, Ohio

Chemical composition:

Both discs were produced from heat B-11728. The chemical composition was reported to be the following percentages by the Universal-Cyclops Steel Corporation:

| C | Mn | Si | P | S | Cr | Ni | Mo | W | Cb | Ti |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.29 | 1.12 | 0.69 | 0.018 | 0.010 | 19.23 | 9.03 | 1.27 | 1.58 | 0.38 | 0.1 |

Fabrication procedure:

The following information, concerned with fabrication of the two discs, was supplied by the manufacturers. Both discs were fabricated the same way with the exception of the temperature of hot-cold-working given in item (9) in the following:

(1) 24,000-pound basic electric-arc heat

(2) $15\frac{1}{2}$- by $15\frac{1}{2}$-inch, 2600-pound ingot with flat sides

(3) $8\frac{1}{2}$- by $8\frac{1}{2}$-inch, 350-pound slugs were used for the individual discs

(4) 2100° F for $1\frac{3}{4}$ hours; 18 blows with 25,000-pound hammer; bottle-die working; air-cooled

(5) 2100° F for 14 hours; 9 blows with 35,000-pound hammer; first blocker; air-cooled

(6) 2100° F for $6\frac{1}{2}$ hours; 14 blows with 35,000-pound hammer; second blocker; air-cooled

(7) Flash machined off and spot ground after bottle-die and second-block operations

(8) Solution treatment: 2150° F for 2 hours; quenched in warm water

(9) Hot—cold—work:

Disc EXC44: 1250° F for 8 hours; 14 blows with 35,000—pound hammer

Disc EXC46: 1700° F for 3 hours; dropped to 1650° F for 3/4 hour; 22 blows with 35,000—pound hammer

(10) Stress—relief anneal: 1200° F for 10 hours; air—cooled

The shape of the contour forgings is shown in figures 1 and 2. The discs were approximately 20 inches in diameter and weighed approximately 325 pounds. The size of the quarter sections tested at the University of Michigan is shown in figure 3.

## EXPERIMENTAL PROCEDURE

The forgings were made at The Canton Drop Forging and Manufacturing Company under carefully controlled and recorded production conditions. Two of the discs prepared, EXC44 and EXC46, were cut in half. The Canton Drop Forging and Manufacturing Company conducted physical tests on the center of each disc. Approximately one—half of each disc was sent to the General Electric Company where similar tests were conducted. Approximately one—quarter of each disc was supplied to the University of Michigan for the NACA program. The other quarters were sent to the Universal-Cyclops Steel Corporation. Data reported by other laboratories have been included in this report. (See figs. 1 and 2 and table I.)

The following testing program for the one—quarter sections furnished the University of Michigan was decided upon:

(1) Tensile tests at room temperature and 1200° F

(2) Rupture tests at 1200° F

(3) Creep tests of 1000—hour duration at 1200° F under stresses of 20,000, 25,000, and 30,000 psi

(4) Hardness, tensile, and rupture tests to show the uniformity of the disc material

(5) Stability tests on the specimens after testing

The major emphasis was placed on the properties of radial specimens from near the rims of the discs because the rim is heated to the highest temperatures during service. Data for stress and time for total deformation were obtained from the elongation curves from the rupture and creep tests. Stability characteristics were estimated by hardness, tensile, and impact tests and by metallographic examination on the specimens after creep and rupture testing.

The test specimens were obtained from coupons cut from the discs according to the diagram of figure 3. This drawing shows the location of the specimens and an identifying code. In the code the letters W, X, Y, and Z refer to the locations of the coupons with respect to the faces of the discs. Tensile and creep tests were conducted on standard 0.505-inch-diameter specimens. Tensile tests from the center portion of the discs were on 0.250-inch-diameter specimens because the shape of the disc section supplied for testing limited the amount of material available in this location. The specimens for rupture tests were of 0.160-inch diameter and were obtained from locations in the large coupons as indicated by the dashed lines in the drawing of figure 3.

## RESULTS

### Hardness Surveys

The disc which had been hot-cold-worked at 1250° F, EXC44, was higher in hardness than disc EXC46, which had been hot-cold-worked at 1650° F. (See figs. 4 and 5 and table II.) Disc EXC44 had a Brinell hardness range of 212 to 287, although most of the hardness values were from 230 to 260. The principal Brinell hardness range for disc EXC46 was 205 to 220. In general the hardness of the discs was higher near the center than near the rim. They also were harder near the two flat surfaces than in the interior. These hardness differences, however, were not so pronounced in EXC46 as in EXC44.

### Short-Time Tensile Properties

The tensile properties at room temperature and 1200° F are summarized in table II.

The tensile and yield strengths of the disc hot-cold-worked at 1250° F were higher at both room temperature and 1200° F than those of disc hot-cold-worked at 1650° F. The 0.02-percent-offset yield strength for EXC44 averaged approximately 70,500 psi while the corresponding strength for EXC46 was 39,000 psi. At 1200° F the 0.2-percent-offset yield strength was approximately 66,000 psi for EXC44 and 43,000 psi for EXC46.

The ductility of disc EXC44 was lower than that of EXC46. At room temperature the elongations of radial specimens from the rims of EXC44 and EXC46 were approximately 26 and 34 percent, respectively, and at 1200° F the elongations were 13 and 29 percent, respectively. The disc hot-cold-worked at 1650° F did not show the marked drop in ductility exhibited by the disc worked at 1250° F when tested at 1200° F.

The properties of specimens from various locations in the discs were quite uniform. The only indication of a marked difference between locations was the lower ductility of center specimens and of tangential specimens from the surface near the rim of the disc worked at 1250° F.

## Rupture Test Characteristics

The rupture test data obtained at 1200° F are given in table III. These data are plotted on double-logarithmic coordinates to give the curves of stress against rupture time in figure 6. The rupture strengths for definite time periods, indicated by figure 6, are included in table III together with the estimated ductilities to fracture. The rupture strengths of disc EXC44, which had been hot-cold-worked at 1250° F, were 47,000 and 38,500 psi for rupture in 100 and 1000 hours. Corresponding strengths for disc EXC46, which had been hot-cold-worked at 1650° F, were 36,500 and 32,000 psi. The ductility to rupture of disc EXC44 was very low, being only 1 to 3 percent for fracture in time periods of 100 to 1000 hours. The comparative ductility of EXC46 ranged from about 20 to 14 percent.

Rupture specimens from various locations in the discs were tested for uniformity at stresses which were expected to cause fracture in approximately 100 hours. The radial specimens from the center of the discs near the rim all ruptured in shorter time periods than the specimens from the four other locations listed in table III. The longest life was obtained from tangential specimens taken near the surface and rim. These tangential specimens lasted 534 and 463 hours for discs EXC44 and EXC46, respectively, as compared with a 100-hour life for center-plane radial specimens near the rim. Rupture test ductilities of the specimens from the four locations were as good as or better than the ductilities on center-plane radial specimens with the exception of the center-plane tangential specimen of disc EXC46 which had very low ductility.

## Time-Deformation Characteristics

Curves of stress against the logarithm of the time required for total deformations of 0.2, 0.5, and 1 percent at 1200° F for the two discs are shown in figures 7 and 8. Curves for rupture time and for the transition to third-stage creep have been added in order to describe completely the deformation characteristics of the two discs. The data for these figures, summarized in table IV, were taken from the time-elongation curves obtained during the creep and rupture tests.

The stresses used in the creep tests were too high to provide sufficient data for a curve for 0.1-percent total deformation. Table IV includes the data for 2- and 5-percent total deformation for disc EXC46. These higher deformation values were not obtained for disc EXC44 because the total deformations of the specimens were less than 2 percent.

In general the disc hot-cold-worked at 1250° F required a higher stress for a given deformation and time period than the disc worked at 1650° F. The difference between the two discs decreased with time, and there was less difference the smaller the total deformation. The stresses to cause various total deformations in 1, 10, 100, 1000, and 2000 hours, as defined by the curves of figures 7 and 8, are summarized and compared in table V.

## Creep Strengths

Data taken from the time-elongation curves for creep tests including total deformation in 100, 500, and 1000 hours and creep rates at 500 and 1000 hours are shown in table VI. The creep rates at 1000 hours were the minimum rates obtained from the tests with the exception of the test at 30,000 psi on disc EXC46, which entered third-stage creep before 1000 hours had elapsed. Minimum creep rates from both the creep and rupture tests are plotted against stress on double-logarithmic coordinates in figure 9. The creep strengths obtained from the curves of figure 9 are as follows:

| Disc | Stress (psi) for creep rates of - | |
|---|---|---|
| | 0.0001 percent/hr | 0.00001 percent/hr |
| EXC44 | 34,500 | 16,000 |
| EXC46 | 27,000 | [a]15,000 |

[a]Estimated.

The creep strengths also show that the superiority of the disc cold-worked at 1250° F decreases with time and with the rate of deformation.

Extrapolation of the transition curves of figures 7 and 8 indicates that increasing creep rates are to be expected on both disc materials at about 2000 or 3000 hours under stresses corresponding to the creep strengths for a rate of 0.0001 percent per hour. This means that it would not be safe to use these creep strengths as a basis for design for longer time periods than 2000 or 3000 hours. The creep strengths for a rate of 0.00001 percent per hour, however, probably can be used safely for much longer time periods.

## Stability Characteristics

Very little change in tensile, impact, and hardness properties at room temperature occurred as a result of creep testing at 1200° F as is shown by the test data in table VII. The original materials were quite responsive to a magnet but responded very little after creep testing at 1200° F.

Photomicrographs of the original material and completed–creep– and rupture–test specimens are shown in figures 10 to 13. The grain size of both discs was 5 to 6, and there was no appreciable difference between the centers and rims. Some of the specimens examined, however, had somewhat larger grain sizes. There were numerous grains which appeared to have a eutectic type of structure. In bar stock these are usually broken up into stringers of excess constituents. In the disc cold-worked at 1650° F, EXC46, these grains of excess constituents were much larger in the center than at the rim.

Some precipitation of fine particles occurred in the structure of both discs during creep and rupture testing at 1200° F. More of this precipitation seemed to appear in the rupture specimens than in the creep specimens. There was remarkably little difference in structure between the specimens from the two discs in spite of the difference in strength and wide difference in ductility. The grains in rupture specimens from disc EXC46 were, of course, elongated in accordance with the high ductility of this disc, while those from disc EXC44 showed no distortion in accordance with the low elongation to fracture.

On the basis of physical properties after testing the indications of structural instability were slight. It is possible that the low ductility of disc EXC44 in the rupture test was due to a structural change during testing. The grains of excess constituents were probably ferrite with precipitated carbides. The disappearance of magnetism after testing at 1200° F suggests that the ferrite was transformed to sigma phase without an appreciable effect on properties.

## Data from Tests in Other Laboratories

Sections from both discs were examined for room-temperature hardness and tensile properties by The Canton Drop Forging and Manufacturing Company and by the General Electric Company. The data reported are summarized in table I and figures 1 and 2. In general these results agreed very well with those given in this report. They have an added advantage in that specimens from very near the center could be tested to show ductility.

The tests by these two companies show that there are soft spots near the stub shaft and near the pilot hub. In disc EXC44 where most of the Brinell hardness values ranged from 250 to 270 the hardness at the soft spots fell to about 210 and 200. In disc EXC46 the soft spots had hardness values as low as 179, while other parts of the disc ranged from 207 to 229.

The ductility of the tensile specimens from the center of the discs was much lower than the radial specimens near the rim. In EXC44, the disc which was hot-cold-worked at 1250° F, specimens taken in the vicinity of the soft spots had elongations as low as 3.5 percent as compared with 20 to 30 percent in other locations in the disc. Soft-spot specimens in disc EXC46, which was hot-cold-worked at 1650° F, had as low as 5.5-percent elongation as compared with 33 to 38 percent in other locations.

## DISCUSSION OF RESULTS

All the data show that the disc EXC44, which was hot-cold-worked at 1250° F, had higher strength than the disc EXC46, which was hot-cold-worked at 1650° F. The higher rupture strength of EXC44 was accompanied by low ductility in the rupture test. These findings are in general agreement with the results to be expected for the two processing procedures. Hot-cold-work at temperatures as high as 1650° F does not produce nearly so high physical properties at room temperature or 1200° F as does hot-cold-work at temperatures below 1500° F. Hot-cold-work at these lower temperatures after a solution-treatment is accompanied by low ductility in the rupture test.

Quite good uniformity of properties was shown by the hardness and tensile data, except for the regions of low hardness, strength, and ductility in the center of the discs. This is a trouble inherent to portions of the forging where the metal is not properly worked during the upsetting operation necessary in the manufacture of such discs. The contour-forging process approaches the maximum possible uniformity of working of the metal, but it is very difficult to develop a suitable procedure that will properly forge certain areas in the centers of the discs.

The rupture strengths appear to be a minimum for specimens taken radially from the center of the discs near the rim. The rupture and creep strengths reported are based on such specimens and are therefore probably conservative.

Rupture specimens from the soft spots in the center of the disc could not be obtained from the quarter section supplied. It is possible that these would have had inferior rupture strength. This is not critical in engines which operate with a cool center.

Extrapolation of the curves of stress against rupture time, time for total deformation, and creep rate suggests that the properties of the disc which was hot-cold-worked at 1650° F would be equal to those of the disc which was hot-cold-worked at 1250° F at time periods of about 10,000 hours. The difference in slope of these curves is probably the result of the difference in structural stability of the materials. The particular structure developed by hot-cold-work at 1250° F is, presumably, less stable than that developed by working at 1650° F.

Properties developed in 19-9DL discs by forging alone are dependent on the heat treatments during heating for forging, the rate of reduction during cooling, and the finishing temperature. In the as-forged condition, therefore, a wide range in properties is theoretically possible. A large cheese forging of 19-9DL previously investigated had properties quite similar to the contour disc worked at 1650° F. (See table VIII.) The contour disc worked at 1250° F had much higher properties, except for low rupture test ductility. A lower finishing temperature or a different rate of reduction with temperature could have changed the comparison, as is indicated by the bar-stock data in table IX.

High ductility in the rupture test seems to be characteristic of the as-forged condition. Apparently the working of the metal at the higher temperatures produces the structure necessary for good elongation at prolonged fracture time periods. Judging from the bar-stock data, a properly controlled forging operation alone could produce a better combination of strength and rupture test ductility than the usual separate hot-cold-working operation.

Data are not available for discs solution-treated and free from cold-work. The bar-stock data in table IX suggest that such discs would have high strength for low rates of deformation and long time periods at 1200° F. Tensile strengths would be low. The ductility in the rupture test would be fairly good.

The information available concerning the contour forgings reported herein does not permit an estimation of the degree of reduction during hot-cold-working. In general, however, the data indicate that the properties of bar stock are reproduced fairly well in large forgings when the processing procedures and heat treatments are similar. The strength of the discs at high temperatures tends to be somewhat lower, probably because it is not possible exactly to duplicate conditions of bar stock in large forgings. Insofar as is yet known, the hot-cold-working and heat treatment have such pronounced effect on properties by developing a size and dispersion of precipitated particles favorable to high-temperature strength. Strain hardening from hot-cold-work is probably an added important influence.

The data for large forgings of other alloys included in table IX from references 2, 3, and 4 show that any comparisons between discs made from different alloys must consider the processing procedure used in their manufacture as well as the chemical composition. The 19-9DL disc hot-cold-worked at 1250° F had lower tensile properties but higher rupture strengths than the contour discs of Timken alloy. Both

19-9DL discs were superior to a disc of hot-forged CSA alloy but were inferior to a disc of low-carbon N-155 alloy. The comparisons would probably change for any of the alloys if the discs were produced under different conditions.

In appraising the data presented in this report, consideration should be given to two factors. The degree of reproducibility of the properties quoted will depend on the control exercised in production. Both higher and lower properties are possible if the processing conditions are allowed to vary. In addition, all the comparisons and analyses have been based on properties at room temperature and 1200° F. The effect of processing conditions on properties changes with temperature, and in particular hot-cold-worked materials rapidly lose their superiority as the service temperature is increased above 1200° F even for time periods less than 1000 hours.

## CONCLUSIONS

From a study of the properties at room temperature and 1200° F of two large contour-forged discs of 19-9DL alloy the following conclusions were made:

1. A solution treatment followed by hot-cold-work at 1250° F produced a higher level of properties in a large contour rotor forging than when the hot-cold-work was done at 1650° F except for lower ductility.

2. Extrapolation of the data predicts that for time periods longer than approximately 10,000 hours the disc which was hot-cold-worked at 1650° F would have properties equal to those of the disc which was hot-cold-worked at 1250° F.

3. Considering their size, the contour-forged discs had excellent uniformity. The discs did, however, have soft spots at the center with relatively low hardness, room-temperature strength, and ductility characteristic of this type of forging. The rupture and creep data reported are probably conservative because they were obtained from radial specimens at the rim which apparently have the lowest strength in the discs.

4. The properties of large discs are quite similar to bar stock when both are heat-treated and hot-cold-worked in a similar manner.

5. Discs made from various alloys cannot be compared on the basis of composition alone. Relative properties vary, depending on the production procedure.

University of Michigan
Ann Arbor, Mich., March 10, 1947

## REFERENCES

1. Freeman, J. W., Reynolds, E. E., and White, A. E.: A Metallurgical Investigation of a Large Forged Disc of 19-9DL Alloy. NACA ACR No. 5C10, 1945.

2. Freeman, J. W., Reynolds, E. E., and White, A. E.: A Metallurgical Investigation of a Large Forged Disc of CSA (234-A-5) Alloy. NACA ARR No. 5H17, 1945.

3. Freeman, J. W., and Cross, H. C.: A Metallurgical Investigation of a Large Forged Disc of Low-Carbon N-155 Alloy. NACA ARR No. 5K20, 1945.

4. Freeman, J. W., Reynolds, E. E., and White, A. E.: A Metallurgical Investigation of Five Forged Gas-Turbine Discs of Timken Alloy. NACA TN No. 1531, 1948.

5. Cross, Howard C., and Freeman, J. W.: A Metallurgical Investigation of Large Forged Discs of Low-Carbon N-155 Alloy. NACA TN No. 1230, 1947.

6. Freeman, J. W., Rote, F. B., and White, A. E.: High Temperature Characteristics of 17 Alloys at 1200° and 1350° F. NACA ACR No. 4C22, 1944.

TABLE I

PHYSICAL PROPERTIES REPORTED BY THE CANTON DROP FORGING AND MANUFACTURING COMPANY ON CONTOUR DISCS OF 19-9DL ALLOY

| Disc EXC44 (Solution-treated; hot-cold-worked at 1250° F) | | | | |
|---|---|---|---|---|
| Sectional Brinell hardness | | | | |
| Principal range | 255-285 | | | |
| Maximum reading | 302 | | | |
| Soft spot at center near stub shaft | 217-229 | | | |
| Soft spot at center near pilot hub | 202-207 | | | |
| Room-temperature tensile properties | | | | |
| Specimen location | Tensile strength (psi) | Yield point (psi) | Elongation (percent) | Reduction of area (percent) |
| Central, horizontal, near stub shaft | 100,000 | 89,500 | 4 | 8.5 |
| Central, horizontal | 117,500 | 96,500 | 9.5 | 14.2 |
| Central, horizontal, near pilot hub | 101,500 | 72,500 | 19.5 | 26.2 |

| Disc EXC46 (Solution-treated; hot-cold-worked at 1650° F) | | | | |
|---|---|---|---|---|
| Sectional Brinell hardness | | | | |
| Principal range | 207-229 | | | |
| Maximum reading | 235 | | | |
| Soft spot at center near stub shaft | 192-197 | | | |
| Soft spot at center near pilot hub | 179-187 | | | |
| Room-temperature tensile properties | | | | |
| Specimen location | Tensile strength (psi) | Yield point (psi) | Elongation (percent) | Reduction of area (percent) |
| Central, horizontal, near stub shaft | 86,000 | 60,000 | 12.5 | 18.5 |
| Central, horizontal | 97,600 | 66,200 | 14.5 | 20.4 |
| Central, horizontal, near pilot hub | 83,000 | 59,000 | 8.5 | 14.9 |

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TABLE II

SHORT-TIME TENSILE PROPERTIES OF CONTOUR DISCS OF 19-9DL ALLOY

| Disc | Specimen number | Specimen location (a) | Temperature (°F) | Tensile strength (psi) | Offset yield strength (psi) | | | Proportional limit (psi) | Elongation in 2 in. (percent) | Reduction of area (percent) | Brinell hardness |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0.02 percent | 0.1 percent | 0.2 percent | | | | |
| EXC44 (Hot-cold-worked at 1250° F) | 3Y | CRR | Room | 118,250 | 70,000 | 85,500 | 91,000 | 47,500 | 24.5 | 31.2 | 252 |
| | 6Y | CRR | Room | 119,375 | 67,500 | 83,500 | 89,500 | 45,000 | 26.5 | 35.6 | 253 |
| | 3X | SRR | Room | 118,500 | 72,000 | 85,000 | 90,000 | 57,500 | 28.0 | 46.9 | 246 |
| | 6Z | SRR | Room | 122,125 | 72,500 | 87,000 | 91,500 | 57,500 | 26.5 | 42.7 | 253 |
| | 9Y | CTR | Room | 115,000 | 68,000 | 81,000 | 86,000 | 50,000 | 29.0 | 36.9 | 236 |
| | 9X | STR | Room | 122,000 | 72,000 | 84,500 | 91,500 | 57,500 | 12.5 | 22.3 | 228 |
| | [b]8XC-1 | CRC | Room | 128,100 | 72,200 | 91,000 | 98,200 | 48,900 | [c]19.0 | 19.7 | --- |
| | [b]8XC-2 | CRC | Room | 116,000 | 65,600 | 84,000 | 92,900 | 44,800 | [c]10.0 | 13.8 | --- |
| | 4Y | CRR | 1200 | 75,000 | ------ | 61,000 | 64,800 | 32,500 | 13.0 | 26.1 | --- |
| | 4X | SRR | 1200 | 77,500 | ------ | 62,000 | 66,500 | 22,500 | 14.5 | 25.3 | --- |
| | 3Z | SRR | 1200 | 73,400 | ------ | ------ | ------ | ------ | 12.5 | 28.4 | --- |
| | 9Z | STR | 1200 | 79,375 | ------ | 63,000 | 67,000 | 37,500 | 8.5 | 14.4 | --- |
| EXC46 (Hot-cold-worked at 1650° F) | 3Y | CRR | Room | 102,250 | 32,000 | 50,000 | 56,750 | 12,500 | 31.5 | 39.4 | 203 |
| | 6Y | CRR | Room | 100,750 | 38,500 | 51,000 | 56,500 | 25,000 | 31.0 | 37.8 | 212 |
| | 3X | SRR | Room | 102,500 | 39,000 | 53,000 | 58,250 | 20,000 | 37.0 | 42.8 | 200 |
| | 6Z | SRR | Room | 104,500 | 47,000 | 56,000 | 60,500 | 35,000 | 34.5 | 47.7 | 215 |
| | 9Y | CTR | Room | 104,750 | 40,500 | 53,000 | 57,000 | 17,500 | 32.0 | 41.6 | 207 |
| | 9Z | STR | Room | 109,750 | 48,000 | 59,000 | 63,500 | 27,500 | 33.0 | 41.0 | 223 |
| | [b]8XC-1 | CRC | Room | 106,900 | 48,900 | 59,000 | 63,500 | 28,500 | [c]35.0 | 31.5 | --- |
| | [b]8XC-2 | CRC | Room | 106,900 | 48,500 | 59,000 | 63,100 | 28,500 | [c]29.0 | 29.5 | --- |
| | 4Y | CRR | 1200 | 57,000 | ------ | 39,000 | 41,800 | 25,000 | 29.0 | 46.3 | --- |
| | 3Z | SRR | 1200 | 56,750 | ------ | 41,500 | 44,000 | 20,000 | 31.0 | 53.2 | --- |

[a]CRR center-plane radial specimen near rim of disc.
SRR surface-plane radial specimen near rim of disc.
CTR center-plane tangential specimen near rim of disc.
STR surface-plane tangential specimen near rim of disc.
CRC center-plane radial specimen near center of disc.
[b]Specimens from center of disc were 0.250-in. in diameter with a 1-in. reduced section.
[c]Elongation, percent in 1 in.

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TABLE III

RUPTURE TEST CHARACTERISTICS AT 1200° F OF CONTOUR DISCS OF 19-9DL ALLOY

| Disc | Specimen number | Specimen location (a) | Stress (psi) | Rupture time (hr) | Elongation in 1 in. (percent) | Reduction of area (percent) |
|---|---|---|---|---|---|---|
| EXC44 (Hot-cold-worked at 1250° F) | 1Y | CRR | 50,000 | 35 | 3.5 | 2.3 |
| | 1Y | CRR | 45,000 | 186 | 2 | 2.3 |
| | 3Y | CRR | 40,000 | 764 | 2 | 3.0 |
| | 3Y | CRR | 37,500 | 1025 | 1 | 2.5 |
| | 4Y | CRR | 36,000 | 1864 | 1 | 5.1 |
| | 4Z | SRR | 47,000 | 517 | 5 | 2.3 |
| | 9Y | CTR | 47,000 | 405 | 3 | 2.6 |
| | 9X | STR | 47,000 | 534 | 2 | 5.0 |
| | 8Y-C | CRC | 47,000 | 215 | 3 | 3.7 |
| EXC46 (Hot-cold-worked at 1650° F) | 3Y | CRR | 40,000 | 31.5 | 25 | 57.8 |
| | 3Y | CRR | 37,500 | 48 | 17 | 48.0 |
| | 3Y | CRR | 36,500 | 69 | 23 | 51.0 |
| | 3Y | CRR | 35,000 | 661 | 19 | 40.8 |
| | 4Y | CRR | 34,000 | 372 | 20 | 49.6 |
| | 1Y | CRR | 32,500 | 820 | 14 | 43.7 |
| | 8Z | SRR | 36,500 | 322 | 23 | 43.2 |
| | 9Y | CTR | 36,500 | 185 | 2 | 2.3 |
| | 9X | STR | 36,500 | 463 | 20 | 46.0 |
| | 8Y-C | CRC | 36,500 | 276 | 19 | 47.4 |

Rupture strength

| Disc | Specimen location (a) | Stress (psi) for rupture in – | | | |
|---|---|---|---|---|---|
| | | 10 hr | 100 hr | 1000 hr | 2000 hr |
| EXC44 | CRR | [b]54,000 | 47,000 | 38,500 | 35,500 |
| EXC46 | CRR | [b]41,000 | 36,500 | 32,000 | [b]31,000 |

Rupture ductility

| Disc | Specimen location (a) | Estimated elongation (percent) to rupture in – | | | |
|---|---|---|---|---|---|
| | | 10 hr | 100 hr | 1000 hr | 2000 hr |
| EXC44 | CRR | 4 | 3 | 1 | 1 |
| EXC46 | CRR | 25 | 20 | 14 | – |

[a]CRR center-plane radial specimen near rim of disc.
SRR surface-plane radial specimen near rim of disc.
CTR center-plane tangential specimen near rim of disc.
STR surface-plane tangential specimen near rim of disc.
CRC center-plane radial specimen near center of disc.
[b]Obtained by extrapolation.

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TABLE IV

DATA ON STRESS AND TIME FOR TOTAL DEFORMATION AT 1200° F FOR CONTOUR DISCS OF 19-9DL ALLOY

| Disc | Specimen number | Stress (psi) | Initial deformation (percent) | Time (hr) for total deformations of – | | | | | | Transition to third-stage creep | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.1 percent | 0.2 percent | 0.5 percent | 1 percent | 2 percent | 5 percent | Time (hr) | Deformation (percent) |
| EX044 (Hot-cold-worked at 1250° F) | 1Y | 20,000 | 0.099 | 1 | [a]3700 | --- | --- | --- | --- | ---- | ---- |
| | 1X | 25,000 | .134 | - | 490 | --- | --- | --- | --- | ---- | ---- |
| | 1Z | 30,000 | .160 | - | 18 | --- | --- | --- | --- | ---- | ---- |
| | 4Y | 36,000 | .175 | - | [b]12 | 700 | --- | --- | --- | 1850 | 0.90 |
| | 3Y | 37,500 | .19 | - | [b]1 | 420 | --- | --- | --- | 990 | .70 |
| | 3Y | 40,000 | .20 | - | ---- | 36 | 520 | --- | --- | 743 | 1.05 |
| | 1Y | 45,000 | .23 | - | ---- | 1 | 120 | --- | --- | 120 | 1.00 |
| | 1Y | 50,000 | .27 | - | ---- | --- | --- | --- | --- | ---- | ---- |
| EX046 (Hot-cold-worked at 1650° F) | 1Y | 20,000 | .091 | 4 | [a]1600 | --- | --- | --- | --- | ---- | ---- |
| | 1X | 25,000 | .127 | - | 132 | --- | --- | --- | --- | ---- | ---- |
| | 1Z | 30,000 | .167 | - | 1 | 685 | --- | --- | --- | 760 | .52 |
| | 1Y | 32,500 | .175 | - | 3 | 13 | 52 | 320 | 722 | 500 | 2.65 |
| | 4Y | 34,000 | .20 | - | ---- | 2 | 19 | 74 | 304 | 140 | 2.5 |
| | 3Y | 35,000 | .21 | - | ---- | --- | 33 | 257 | 531 | 225 | 1.8 |
| | 3Y | 36,500 | .23 | - | ---- | --- | 1 | 18 | 47 | ---- | ---- |
| | 3Y | 37,500 | .25 | - | ---- | --- | --- | [b]12 | [b]26 | ---- | ---- |
| | 3Y | 40,000 | .32 | - | ---- | --- | --- | [b]5 | [b]17 | ---- | ---- |

[a]Obtained by extrapolation from creep curve.
[b]Estimated from rupture curve.

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TABLE V

TIME-DEFORMATION STRENGTHS AT 1200° F OF CONTOUR DISCS OF 19-9DL ALLOY

| Disc | Total deformation (percent) | Stress (psi) to cause total deformation in – | | | | |
|---|---|---|---|---|---|---|
| | | 1 hr | 10 hr | 100 hr | 1000 hr | 2000 hr |
| EXC44 (Hot-cold-worked at 1250° F) | 0.2 | 38,000 | 33,000 | 28,400 | 23,500 | [a]22,000 |
| | .5 | 45,000 | 41,800 | 38,700 | 35,800 | ------ |
| | 1.0 | ------ | ------ | 45,500 | 38,000 | ------ |
| | Transition | ------ | ------ | 46,000 | 38,000 | ------ |
| EXC46 (Hot-cold-worked at 1650° F) | 0.2 | 31,000 | 28,000 | 25,000 | 21,500 | [a]20,500 |
| | .5 | 34,500 | 32,900 | 31,200 | 29,800 | ------ |
| | 1.0 | 36,300 | 34,600 | 32,800 | ------ | ------ |
| | Transition | ------ | ------ | 36,000 | 30,300 | ------ |

[a]Estimated.

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TABLE VI

CREEP TEST DATA AT 1200° F FOR CONTOUR DISCS OF 19-9DL ALLOY

| Disc | Creep test conditions | | Initial deformation (percent) | Total deformation (percent) at – | | | Creep rate (percent/hr) at – | |
|---|---|---|---|---|---|---|---|---|
| | Stress (psi) | Duration (hr) | | 100 hr | 500 hr | 1000 hr | 500 hr | 1000 hr |
| EXC44 (Hot-cold-worked at 1250° F) | 20,000 | 1006 | 0.099 | 0.125 | 0.150 | 0.164 | 0.000030 | 0.000016 |
| | 25,000 | 1005 | .134 | .170 | .200 | .221 | .000050 | .000025 |
| | 30,000 | 1129 | .160 | .233 | .280 | .305 | .000075 | .000035 |
| EXC46 (Hot-cold-worked at 1650° F) | 20,000 | 1006 | .091 | .128 | .158 | .180 | .000045 | .000030 |
| | 25,000 | 1006 | .127 | .193 | .242 | .282 | .000085 | .000070 |
| | 30,000 | 1124 | .167 | .328 | .450 | .600 | .000270 | .000340 |

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TABLE VII

EFFECT OF CREEP TESTING AT 1200° F ON THE ROOM-TEMPERATURE PHYSICAL PROPERTIES OF CONTOUR DISCS OF 19-9DL ALLOY

| Disc | Specimen number | Prior testing conditions | | Residual room-temperature properties | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Stress (psi) | Time (hr) | Tensile strength (psi) | Offset yield strength (psi) | | | Proportional limit (psi) | Elongation in 2 in. (percent) | Reduction of area (percent) | Izod impact strength (ft-lb) (a) | Vickers hardness |
| | | | | | 0.02 percent | 0.1 percent | 0.2 percent | | | | | |
| EXC44 (Hot-cold-worked at 1250° F) | (b) | (c) | (c) | 119,600 | 70,500 | 85,300 | 90,500 | 51,900 | 26 | 39 | 20, 20 | [d]242-247 [e]269 |
| | 1Z | 30,000 | 1129 | ------- | ------ | ------ | ------ | ------ | ---- | ---- | 28, 33 | 290 |
| | 1X | 25,000 | 1005 | 127,250 | 60,000 | 78,000 | 86,000 | 25,000 | 24.5 | 43.1 | ------ | --- |
| | 1Y | 20,000 | 1006 | 124,000 | 66,000 | 81,000 | 86,200 | 35,000 | 21.5 | 27.2 | ------ | --- |
| EXC46 (Hot-cold-worked at 1650° F) | (b) | (c) | (c) | 102,500 | 39,000 | 52,500 | 58,000 | 23,100 | 34 | 42 | 27, 29 | [d]210-216 [e]227 |
| | 1Z | 30,000 | 1124 | ------- | ------ | ------ | ------ | ------ | ---- | ---- | 31, 33 | 226 |
| | 1X | 25,000 | 1006 | 103,750 | 42,000 | 52,000 | 58,000 | 25,000 | 29.5 | 37.1 | ------ | --- |
| | 1Y | 20,000 | 1006 | 104,000 | 42,000 | 54,000 | 58,800 | 27,500 | 28.0 | 25.1 | ------ | --- |

[a]Impact-specimen size: 0.365-in. square with a 0.050-in.-deep V-notch.
[b]Average of tests on center and surface specimens at rim of disc.
[c]Original condition.
[d]Center rim.
[e]Center.

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TABLE VIII

COMPARATIVE PROPERTIES OF THREE LARGE DISCS OF 19-9DL ALLOY

| Type forging | Contour disc EXC44 | Contour disc EXC46 | 20-inch-diameter cheese forging (a) |
|---|---|---|---|
| Heat number | B11728 | B11728 | B10429 |
| Chemical composition, percent: | | | |
| C | 0.29 | 0.29 | 0.33 |
| Mn | 1.12 | 1.12 | 1.14 |
| Si | 0.69 | 0.69 | 0.65 |
| Cr | 19.23 | 19.23 | 19.10 |
| Ni | 9.03 | 9.03 | 9.05 |
| Mo | 1.27 | 1.27 | 1.35 |
| W | 1.58 | 1.58 | 1.14 |
| Cb | 0.38 | 0.38 | 0.35 |
| Ti | 0.43 | 0.43 | 0.16 |
| Fabrication | Hot-forged; 2150° F 2 hr, water-quenched; hot-cold-worked at 1250° F; 1200° F, air-cooled. | Hot-forged; 2150° F, 2 hr, water-quenched; hot-cold-worked at 1650° F; 1200° F, air-cooled. | Hot-forged to 1640° F; 1200° F, air-cooled. |
| Brinell hardness | [b]246-253 | [b]200-223 | [b]202-208 |
| Room-temperature tensile properties: | | | |
| Tensile strength, psi | [b]119,600 | [b]102,500 | [b]104,700 |
| 0.02-percent-offset yield strength, psi | [b]70,500 | [b]39,000 | [b]39,275 |
| 0.1-percent-offset yield strength, psi | [b]85,250 | [b]52,500 | [b]50,400 |
| 0.2-percent-offset yield strength, psi | [b]90,500 | [b]58,000 | [b]54,700 |
| Elongation, percent in 2 in. | [b]26 | [b]34 | [b]30.2 |
| Reduction of area, percent | [b]39.1 | [b]41.9 | [b]30.7 |
| Tensile properties at 1200° F: | | | |
| Tensile strength, psi | 75,300 | 56,875 | 57,875 |
| 0.2-percent-offset yield strength, psi | 65,650 | 42,900 | 37,900 |
| Elongation, percent in 2 in. | 13.3 | 30 | 34.0 |
| Reduction of area, percent | 26.6 | 49.8 | 47.5 |
| Rupture characteristics at 1200° F: | | | |
| 100-hr rupture strength, psi | 47,000 | 36,500 | 40,000 |
| 100-hr rupture elongation, percent in 1 in. | 3 | 20 | 27 |
| 1000-hr rupture strength, psi | 38,500 | 32,000 | 34,000 |
| 1000-hr rupture elongation, percent in 1 in. | 1 | 14 | 16 |
| Time-deformation strengths at 1200° F, psi: | | | |
| 0.1 percent in 10 hr | ------ | ------ | 16,000 |
| 0.1 percent in 100 hr | ------ | ------ | 14,000 |
| 0.1 percent in 1000 hr | ------ | ------ | 12,000 |
| 0.2 percent in 10 hr | 33,000 | 28,000 | 24,000 |
| 0.2 percent in 100 hr | 28,400 | 25,000 | 21,000 |
| 0.2 percent in 1000 hr | 23,500 | 21,500 | 17,000 |
| 0.5 percent in 10 hr | 41,800 | 32,900 | 29,000 |
| 0.5 percent in 100 hr | 38,700 | 31,200 | 26,000 |
| 0.5 percent in 1000 hr | 35,800 | 29,800 | 23,500 |
| 1 percent in 10 hr | ------ | 34,600 | 32,500 |
| 1 percent in 100 hr | 45,500 | 32,800 | 29,000 |
| 1 percent in 1000 hr | 38,000 | ------ | 26,000 |
| Transition in 100 hr | 46,000 | 36,000 | 39,000 |
| Transition in 1000 hr | 38,000 | 30,300 | 33,000 |
| Creep strengths at 1200° F, psi: | | | |
| 0.00001 percent/hr | 16,000 | [c]15,000 | 11,000 |
| 0.0001 percent/hr | 34,500 | 27,000 | 25,000 |

[a]Data from reference 1.
[b]Average values for radial specimens.
[c]Estimated.

TABLE IX

COMPARATIVE PROPERTIES OF DISCS AND BAR STOCK OF 19-9DL ALLOY AND DISCS OF CSA, LOW-CARBON N-155, AND TIMKEN ALLOYS

| Type material | Heat number | Processing: Heat treatment: Temperature (°F) | Heat treatment: Time (hr) | Heat treatment: Cooling (2) | Hot-cold-work: Temperature (°F) | Hot-cold-work: Reduction (percent) | Final treatment: Temperature (°F) | Final treatment: Time (hr) | Room-temperature physical properties (1): Tensile strength (psi) | Yield strength (psi): 0.02 percent | Yield strength (psi): 0.2 percent | Elongation (percent) | Brinell hardness | Rupture properties at 1200° F for – 100 hr: Strength (psi) | 100 hr: Elongation (percent) | 1000 hr: Strength (psi) | 1000 hr: Elongation (percent) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Contour disc EK044 | E11728 | 2150 | 2 | W.Q. | 1250 | (3) | 1200 | 10 | 119,600 | 70,500 | 90,500 | 26 | 246-253 | 47,000 | 3 | 38,500 | 1 |
| Contour disc EK046 | E11728 | 2150 | 2 | W.Q. | 1650 | (4) | 1200 | 10 | 102,500 | 39,000 | 58,000 | 34 | 200-223 | 36,500 | 20 | 32,000 | 14 |
| Disc (cheese forging)[5] | E10429 | (6) | (6) | (6) | ---- | ----- | 1200 | (7) | 104,700 | 39,275 | 54,700 | 30.2 | 202-208 | 40,000 | 27 | 34,000 | 16 |
| Bar stock[8] | A10753 | (9) | (9) | (9) | ---- | ----- | ---- | --- | 114,000 | 45,500 | 68,225 | 35 | 211-241 | 43,000 | 20 | 36,000 | 30 |
| Bar stock[10] | N163 | (9) | (9) | (9) | ---- | ----- | 1200 | (7) | 117,000 | 54,500 | 67,750 | 56 | 214-218 | 47,000 | 16 | 37,000 | 14 |
| Bar stock[8] | E10429 | (9) | (9) | (9) | 1200 | 20 | 1200 | 1 | 154,200 | 100,250 | 125,000 | 24 | 321-335 | 55,000 | 2 | 37,500 | 3 |
| Bar stock[8] | E10429 | 2100 | 1 | W.Q. | ---- | ----- | 1200 | 1 | 102,000 | 26,500 | 42,250 | 53 | 186-189 | 42,000 | 12 | 35,000 | 10 |
| Bar stock[8] | A10753 | 2050 | 2 | W.Q. | ---- | ----- | 1200 | 1 | 104,250 | 39,000 | 48,000 | 56 | 194 | 43,000 | 12 | 37,500 | 8 |
| Bar stock[8] | A10753 | 2200 | 1 | W.Q. | 1200 | 10 | 1200 | 1 | 124,000 | 68,300 | 91,500 | 32 | 252 | 55,000 | 1 | 46,000 | 3 |
| Bar stock[8] | A10753 | 2050 | 2 | W.Q. | 1200 | 10 | 1200 | 1 | 122,380 | 63,000 | 93,100 | 33 | 248 | 49,000 | 10 | 45,000 | 4 |
| Bar stock[11] | E1803 | 2100 | 1 | A.C. | 1200 | 21.35 | 1200 | 1 | 168,750 | 95,000 | 113,750 | 29 | 289 | 62,000 | 5 | 50,000 | 3 |
| CSA disc[12] | 1X2218 | (13) | (13) | (13) | ---- | ----- | 1200 | 4 | 107,400 | 40,300 | 58,300 | 35 | 204-215 | 35,500 | 32 | 30,000 | 18 |
| Low-carbon N-155 disc[14] | A11534 | (13) | (13) | (13) | ---- | ----- | 1200 | 2 | 118,290 | 58,750 | 72,650 | 35 | 211-255 | 55,000 | 12 | 42,000 | 10 |
| [15]Timken contour disc S451 | H-4315 | (13) | (13) | (13) | 1200 to 1300 | (16) | 1200 | (7) | 122,780 | 76,400 | 92,900 | 14 | 250-261 | 45,500 | 18 | 34,000 | 10 |
| [15]Timken contour disc 03B-441 | 13060 | 2150 | 2 | W.Q. | 1250 | (16) | 1200 | 10 | 135,750 | 81,000 | 100,100 | 20 | 269-299 | 44,000 | 2 | 34,000 | 3 |
| [15]Timken contour disc S1509 | H-4684 | (13) | (13) | (13) | 1275 | (16) | 1200 | (7) | 123,875 | 72,500 | 95,500 | 18 | 248-267 | 49,000 | 30 | 34,000 | 30 |

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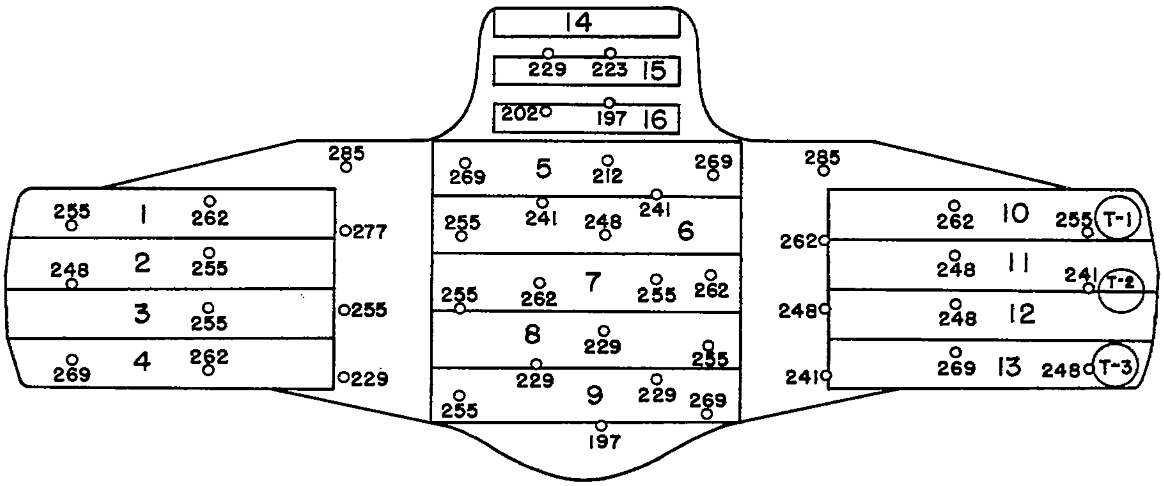
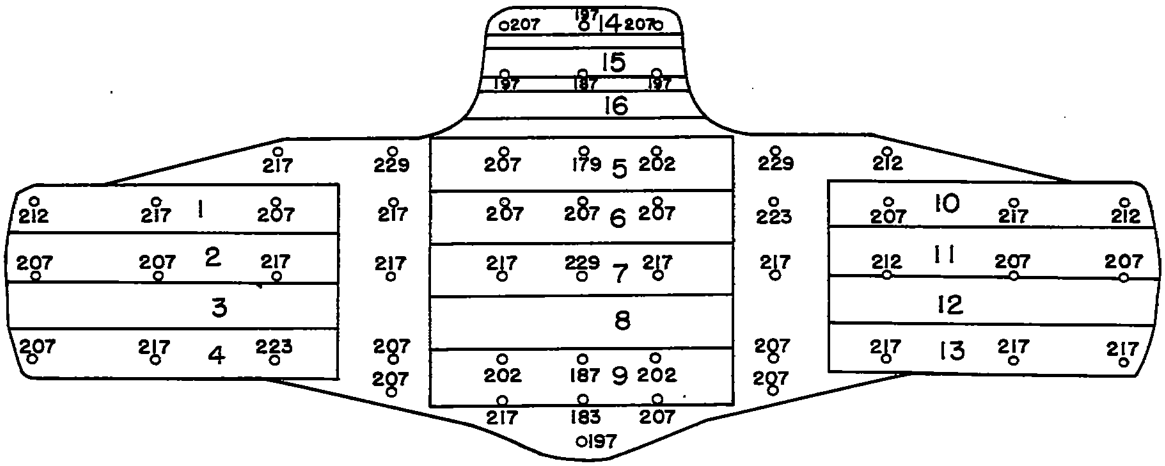
[1]Average for radial specimens on discs.
[2]W.Q. water-quenched,
A.C. air-cooled.
[3]14 hammer blows.
[4]22 hammer blows.
[5]See reference 1.
[6]Hot-forged to 1640° F.
[7]Time of stress relief not known.
[8]Unpublished data from the University of Michigan.
[9]Hot-rolled.
[10]Data furnished by the Universal-Cyclops Steel Corporation.
[11]See reference 6.
[12]See reference 2.
[13]Hot-forged.
[14]See reference 3.
[15]See reference 4.
[16]Amount of hot-cold-work not known.




| 0.505-in. bars pulled at room temperature | | | | |
|---|---|---|---|---|
| Bar | 0.0002-percent-offset yield strength (psi) | Tensile strength (psi) | Elongation (percent) | Reduction of area (percent) |
| 1 | 73,500 | 118,500 | 28 | 48.58 |
| 2 | 71,625 | 119,000 | 27 | 36.62 |
| 3 | 72,000 | 119,000 | 20.5 | 38.50 |
| 4 | 73,875 | 121,500 | 27.5 | 47.44 |
| 5 | 64,875 | 96,000 | 3.5 | 11.89 |
| 6 | 63,000 | 103,500 | 16.5 | 24.76 |
| 7 | 73,500 | 122,000 | 12.5 | 13.38 |
| 8 | 65,250 | 104,000 | 8 | 12.26 |
| 9 | 61,500 | 104,000 | 6*** | 9.27 |
| 10 | 73,500 | 116,500 | 25 | 48.87 |
| 11 | 70,875 | 116,000 | 27.5 | 36.94 |
| 12 | 68,625 | 117,500 | 27.5 | 39.12 |
| 13 | 76,500 | 121,500 | 25 | 46.32 |
| T-1 | 76,500 | 123,500 | 21.5 | 25.10 |
| T-2 | 73,500 | 118,000 | 29 | 40.96 |
| T-3 | 72,000 | 118,000 | 30.5 | 41.57 |
| 0.250-in. bars pulled at room temperature | | | | |
| 14 | 58,212 | 92,400 | 5*** | 10.81 |
| 15 | 52,700 | 100,000 | 13 | 18.97 |
| 16 | 57,600 | 81,600 | 7 | 18.16 |

***Broke near measured section.

Figure 1.- Data from General Electric Company on disc EXC44 of 19-9DL alloy.




| 0.505-in. bars pulled at room temperature | | | | |
|---|---|---|---|---|
| Bar | 0.0002-percent-offset yield strength (psi) | Tensile strength (psi) | Elongation (percent) | Reduction of area (percent) |
| 1 | 48,000 | 100,000 | 35 | 43.38 |
| 2 | 45,750 | 100,500 | 33 | 36.62 |
| 3 | 44,250 | 100,500 | 36 | 46.32 |
| 4 | 47,625 | 104,500 | 36.5 | 50.29 |
| 5 | 37,500 | 79,500 | 9 | 10.40 |
| 6 | 42,000 | 78,000 | 5.5 | 12.26 |
| 7 | 50,625 | 103,500 | 22.5 | 25.79 |
| 8 | 43,125 | 89,000 | 11 | 13.74 |
| 9 | 38,250 | 83,000 | 12 | 16.66 |
| 10 | 48,000 | 101,000 | 35.5 | 43.38 |
| 11 | 45,000 | 101,500 | 34 | 43.38 |
| 12 | 43,500 | 101,000 | 36 | 43.97 |
| 13 | 46,125 | 104,000 | 38 | 50.29 |
| 0.250-in. bars pulled at room temperature | | | | |
| 14 | 43,426 | 94,300 | 14[x] | 13.06 |
| 15 | 41,270 | 88,800 | 14 | 16.73 |
| 16 | 39,812 | 89,800 | 18 | 19.59 |

[x]Broke outside measured section.

Figure 2.- Data from General Electric Company on disc EXC46 of 19-9DL alloy.

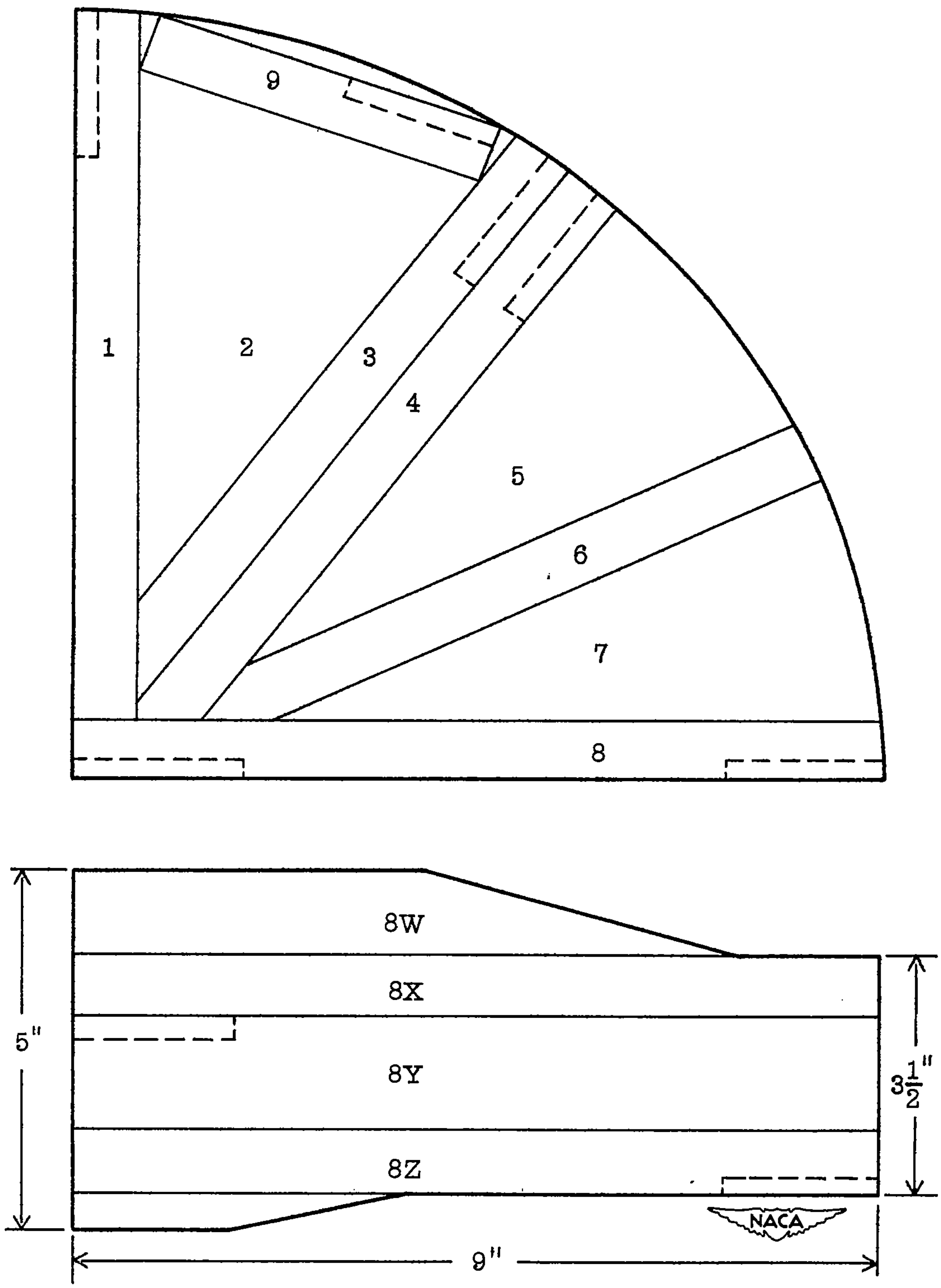



Figure 3.- Diagram showing location of test coupons in quarter sections of contour discs EXC44 and EXC46 of 19-9DL alloy.

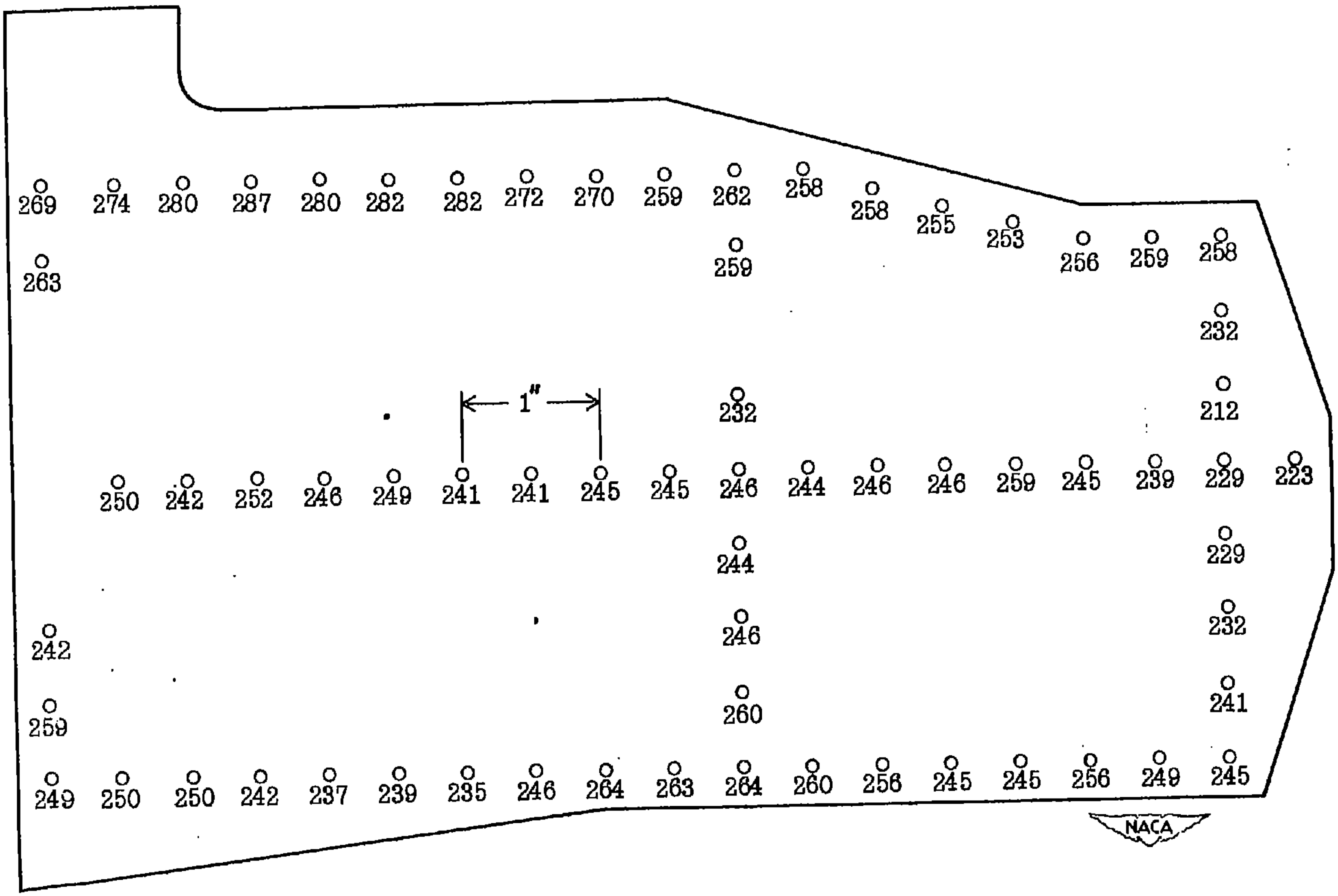



Figure 4.- Hardness survey on a half section of contour disc EXC44 of 19-9DL alloy. Brinell hardness; disc section 8.

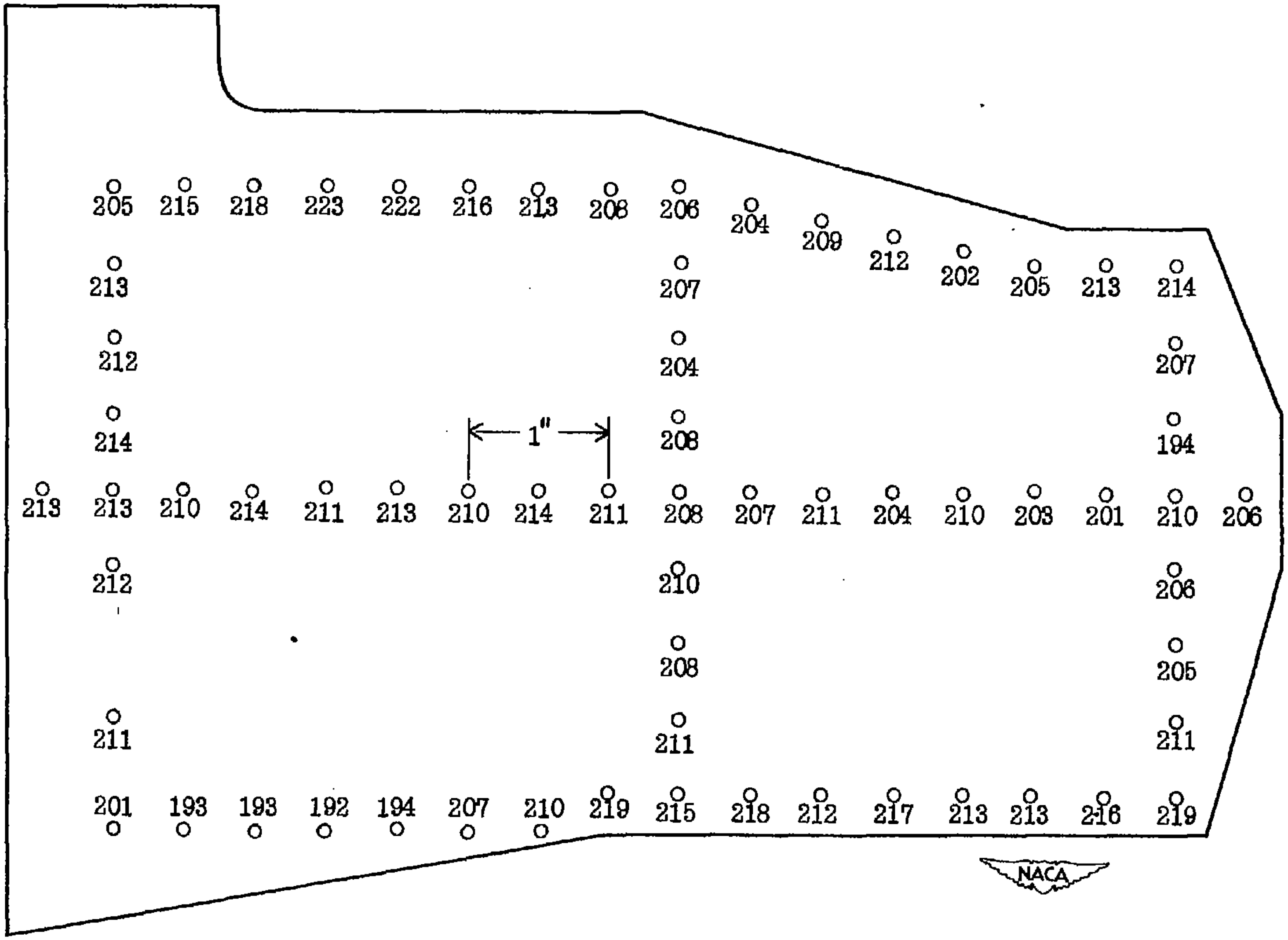



Figure 5.- Hardness survey on a half section of contour disc EXC46 or 19-9DL alloy. Brinell hardness; disc section 8.

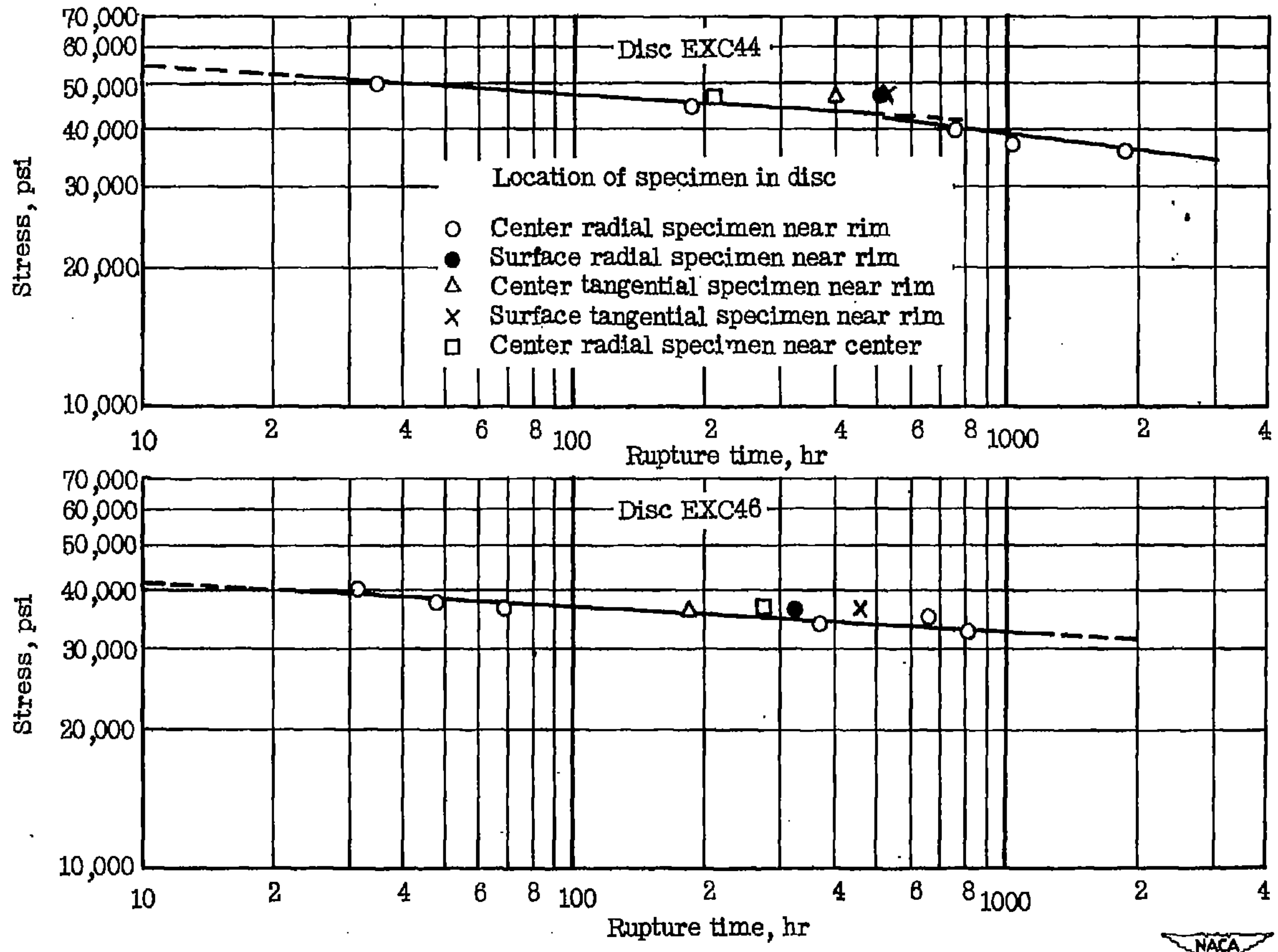



Figure 6.- Curves of stress against rupture time at 1200° for contour discs of 19-9DL alloy.

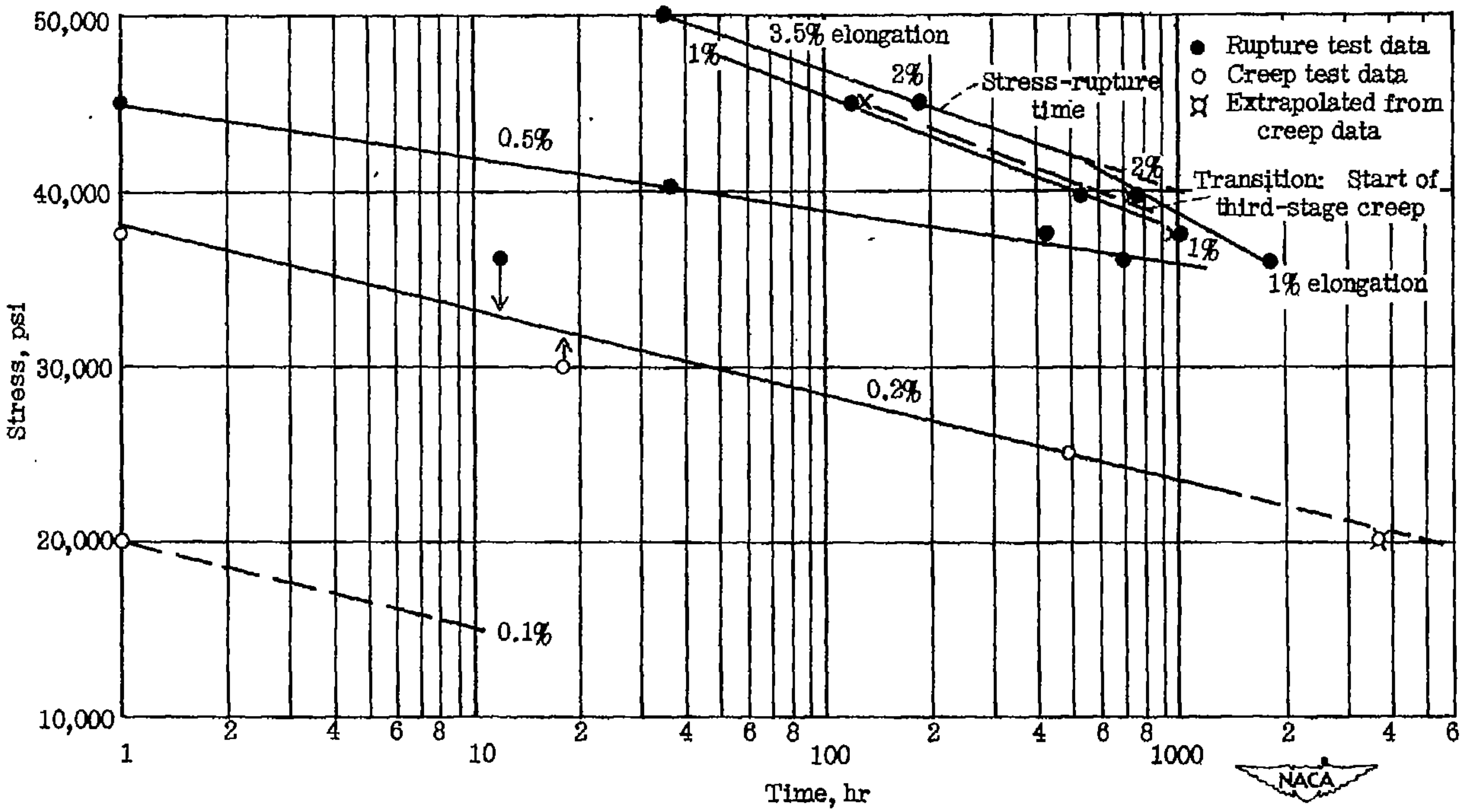



Figure 7.- Curves of stress against time for total deformation at 1200° F for contour disc EXC44 of 19-9DL alloy. (Treatment: Forged; solution-treated; hot-cold-worked at 1250° F; stress-relieved.)

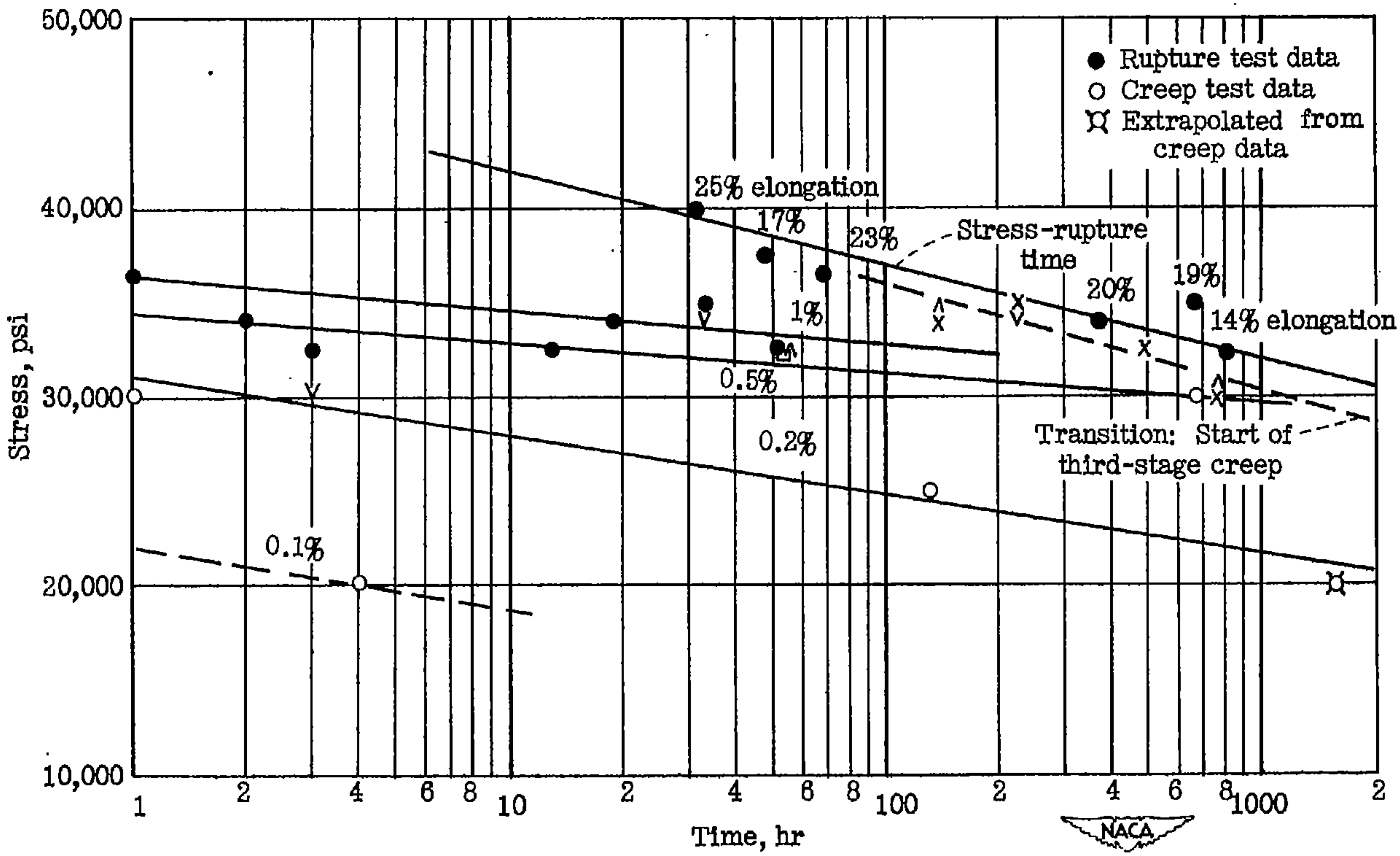



Figure 8.- Curves of stress against time for total deformation at 1200° F for contour disc EXC46 of 19-9DL alloy. (Treatment: Forged; solution-treated: hot-cold-worked at 1650° F; stress-relieved.)

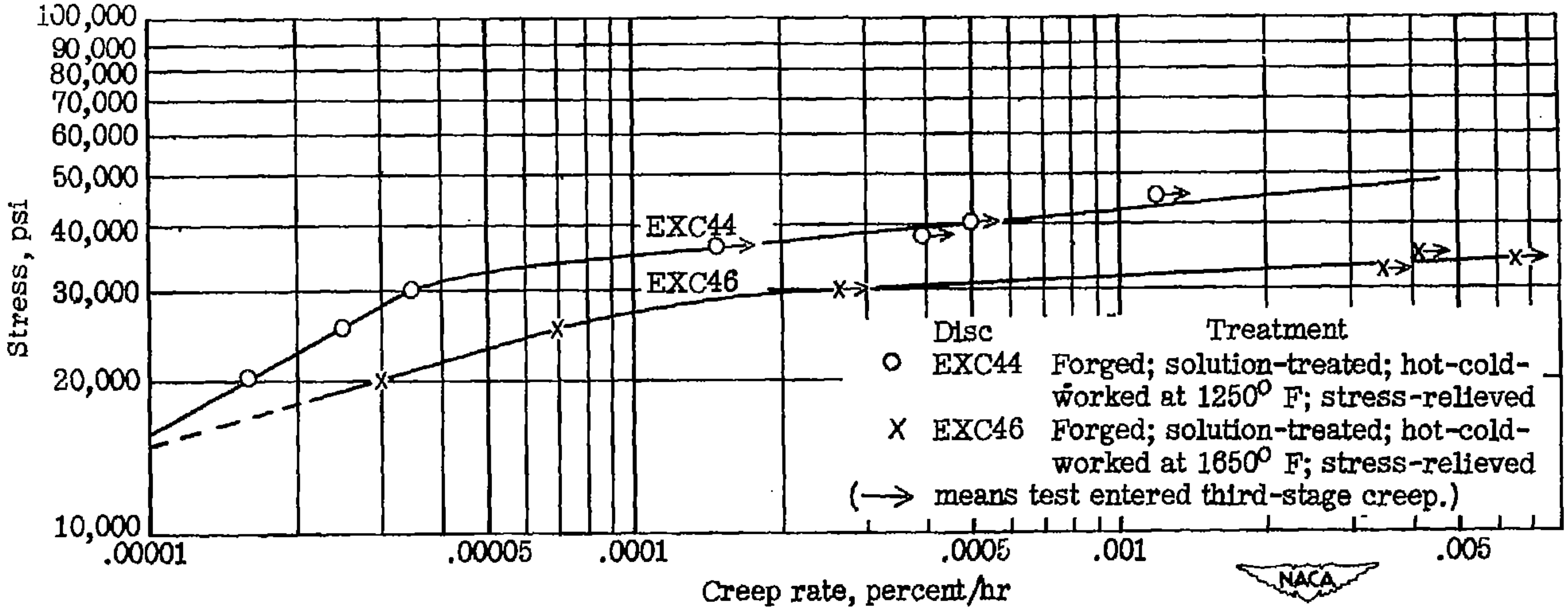
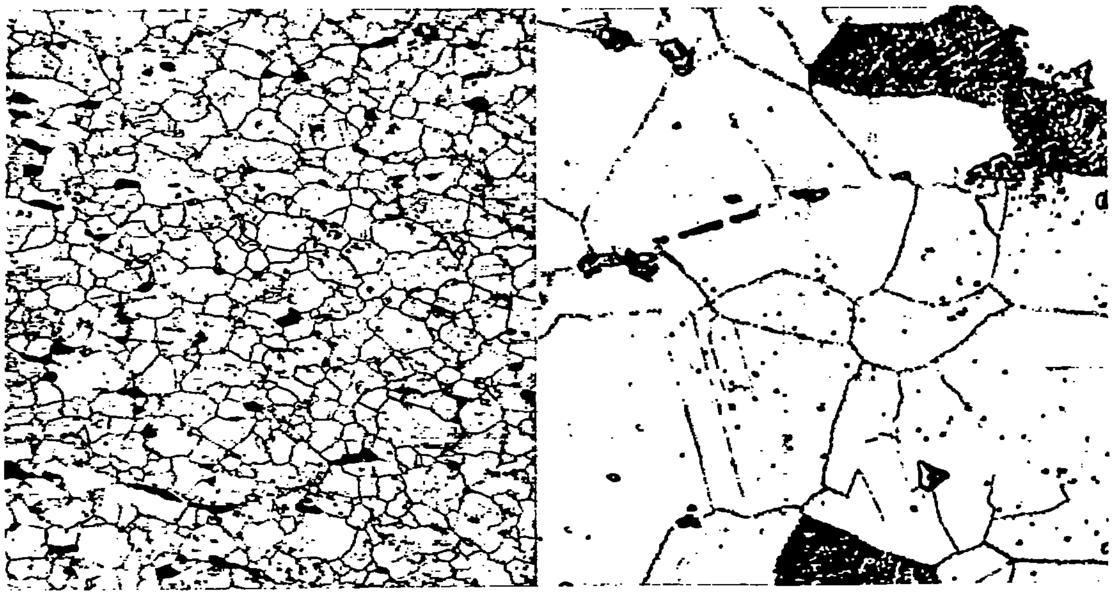
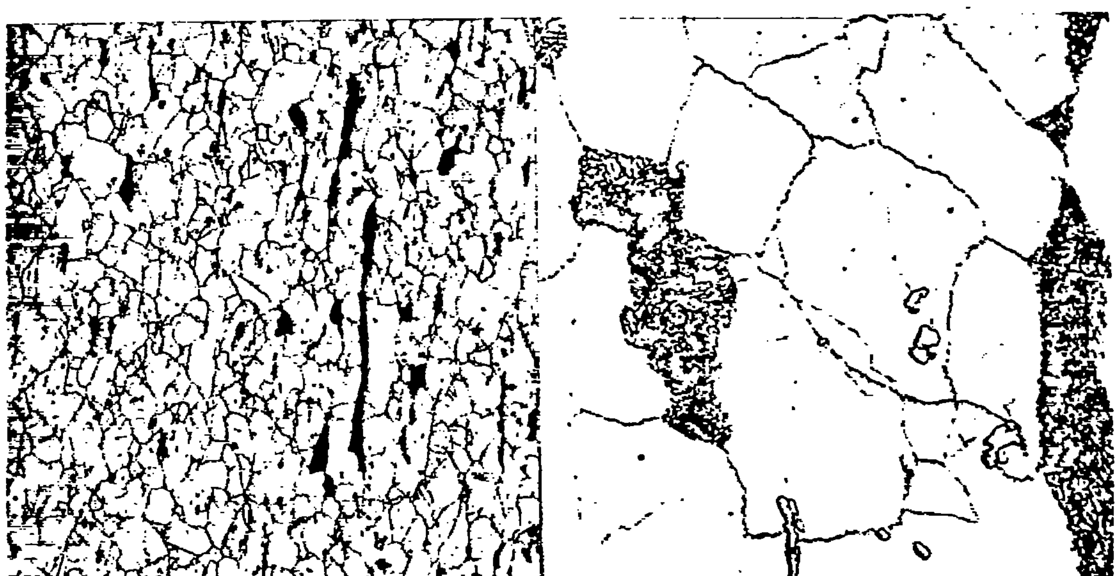



Figure 9.- Curves of stress against creep rate at 1200° F for contour discs of 19-9DL alloy. All data at stresses above 30,000 psi from rupture tests.



100X 1000X

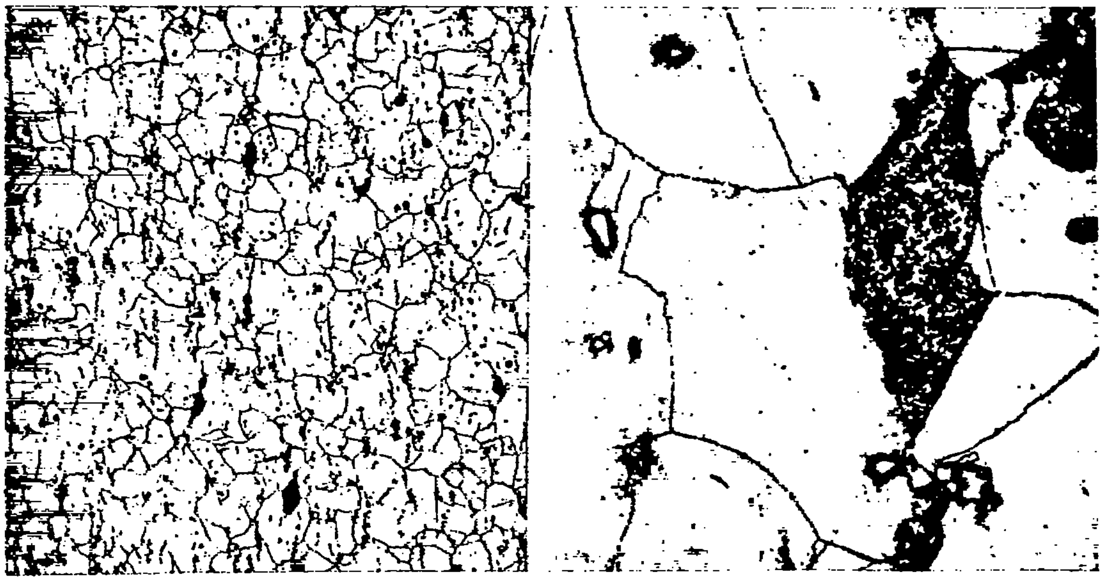
(a) Radial section near rim of disc in Y-plane.



100X 1000X

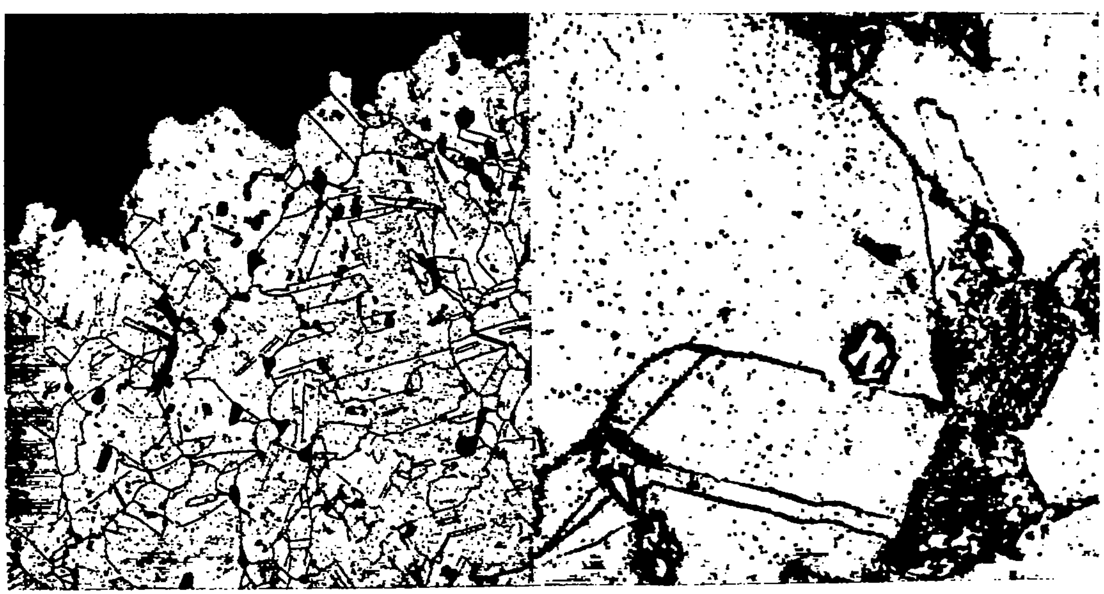
(b) Radial section near center of disc in Y-plane.

Figure 10.- Original microstructure of contour disc EXC44 of 19-9DL alloy.



100X 1000X

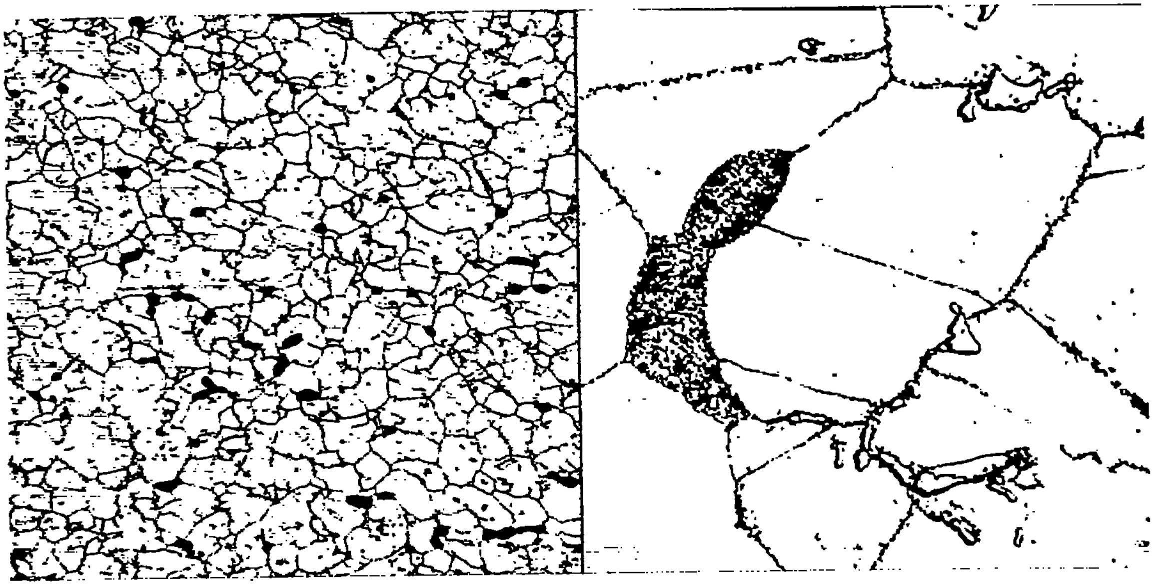
(a) Creep specimen 1Z; 1129 hours under 30,000 psi.



Fracture - 100X Interior - 1000X

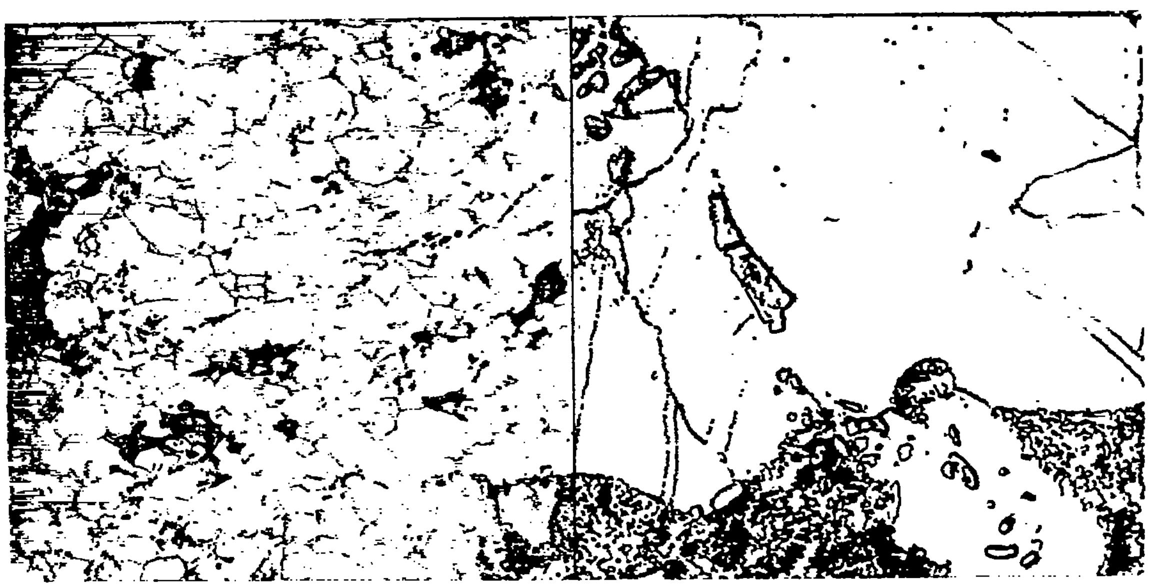
(b) Rupture specimen 4Y; 1864 hours for rupture under 36,000 psi.

Figure 11.- Microstructures of completed 1200° F creep- and rupture-test specimens from contour disc EXC44 of 19-9DL alloy.



100X 1000X

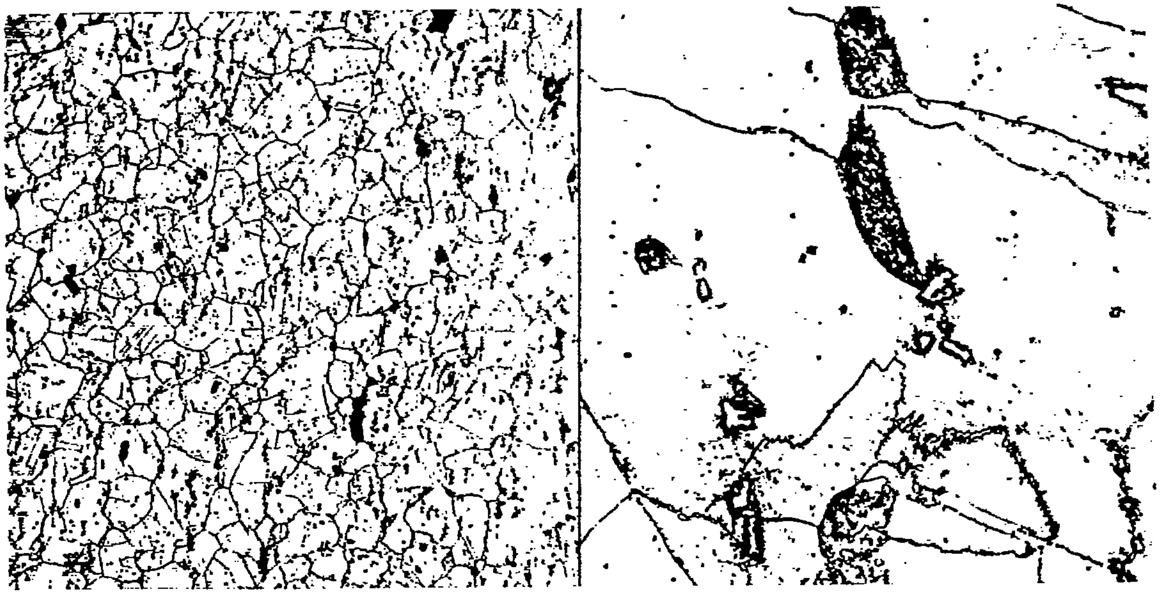
(a) Radial section near rim of disc in Y-plane.



100X 1000X

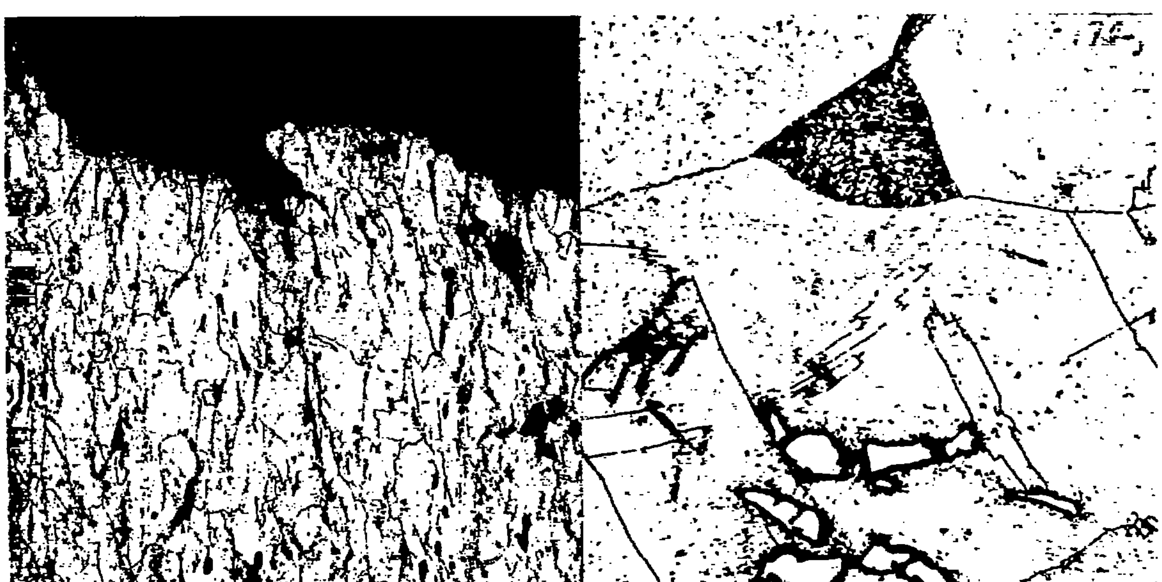
(b) Radial section near center of disc in Y-plane.

Figure 12.- Original microstructure of contour disc EXC46 of 19-9DL alloy.



100X 1000X

(a) Creep specimen 1Z; 1124 hours under 30,000 psi.



Fracture - 100X Interior - 1000X

(b) Rupture specimen 1Y; 820 hours for rupture under 32,500 psi.

Figure 13.- Microstructures of completed 1200° F creep- and rupture-test specimens from contour disc EXC46 of 19-9DL alloy.